PRE-ENGINEERING ASSESSMENT

OF

ENERSOLVE DEMONSTRATION PROJECT - DAIRY PROCESSING PLANT

FINAL REPORT

BY

SNC INC.

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SOMMAIRE

La première phase du projet expérimental ENERSOLVE, qui en comporte 4, a porté sur une évaluation d'ingénierie préliminaire, englobant l'étude des économies d'énergie réalisables dans une laiterie puis la stratégie à suivre pour y parvenir après modernisation et réfection.

C'est sur l'usine de la Coopérative agro-alimentaire Agropur située à Notre-Dame-Du-Bon-Conseil (Québec), où l'on produit fromages et petit lait, que le choix s'est fixé à titre d'installation représentative de l'ensemble de l'industrie laitière du Canada.

L'évaluation d'ingénierie préliminaire a commencé par une étude des installations et de leur fonctionnement, un inventaire des appareils et des étapes du procédé de transformation où des économies substantielles pourraient être réalisées suite à diverses modernisations. L'étape suivante a porté sur une estimation des frais qu'entraineraient l'ingénierie, l'approvisionnement, la gestion de la construction et la surveillance des appareils ainsi modernisés.

La laiterie comprend 3 chaudières, dont une de vapeur atomisée Babcock & Wilcox, fonctionnant au pétrole qui est la plus grosse des 3 et qui offre les meilleures possibilités d'amélioration.

Nous avons proposé les améliorations suivantes:

- Installer un économiseur de gaz de carneau pour en récupérer la chaleur et pré-chauffer l'eau d'alimentation de la chaudière.

- Remplacer le gazoil n° 6 par du gaz naturel dans la chaudière et changer le brûleur pour un brûleur moderne, utilisant moins d'air en excès.

- Modifier le parcours du biogaz provenant du brûleur d'effluents gazeux de la chaudière B & W vers le nouveau brûleur, ce qui permettra une régulation supérieure du débit d'air en excès dirigé vers la chaudière, et donc de simplifier la disposition du brûleur.

En supposant le prix de l'énergie à 5.5205 $/GJ, les économies ainsi réalisées devraient pouvoir atteindre autour de 3.488 Gj/h soit 125 000 $/an. De plus, en remplaçant le gazoil n° 6 par du gaz naturel, on pourrait atteindre une économie nette de 374 000 $/an, si l'on calcule le prix du combustible à 4.8713 $/GJ.

L'investissement nécessité pour ces modifications étant évalué à 346 000 $, il pourrait être amorti sur 12 à 18 mois selon les dispositions financières et la consommation énergétique réelle de l'usine.

SUMMARY

A pre-engineering assessment was carried out in Phase I of a four phase ENERSOLVE demonstration project. The study involved evaluation of a dairy processing plant to demonstrate energy conservation potential and developing a strategy to realize energy savings through retrofitting and revamping.

The cheese and whey making plant of Agropur Coopérative Agro-Alimentaire located at Notre-Dame-du-Bon-Conseil, Québec was selected as a representative Canadian dairy processing plant.

The pre-engineering assessment included a review of existing facility at the plant and plant operation, identification of plant equipment or process steps where substantial economic benefits would result from retrofitting and revamping, and estimation of budgetary cost for the subsequent engineering, procurement, construction management and monitoring of the retrofitted equipment.

The steam-atomized oil-fired Babcock & Wilcox package boiler, which is the largest of the three installed boilers and the main source of process steam, offers the best potential for energy conservation at this plant.

The following recommendations have been proposed:-

- Installation of a flue gas economizer to recover the heat energy in the gas by preheating boiler feed water.

- Substitution of #6 Fuel Oil by natural gas as boiler fuel and replacement of the present oil burner by a modern low excess-air burner unit.

- Rerouting of the biogas gas from the separate waste gas burner on the B & W boiler to the proposed burner unit to provide better control of excess air flow to the boiler and to simplify the burner arrangement.

It has been estimated that the proposed modificataions would result in approximate heat savings of 3.488 GJ/h or $125 000 per year at an energy cost of $5.5205/GJ. Moreover, if natural gas is substituted for Fuel Oil No. 6 net savings could amount to $374 000 per annum at an energy cost of $4.8713/GJ. The capital required for implementing the proposed modifications is estimated to be $346 000. The payback period for proposed modification would be about one year to one-and-a-half years depending upon the financing arrangements and the actual energy consumption at the plant.

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1.0 INTRODUCTION

1.0 INTRODUCTION

The present work was carried out for CANMET, Energy Research Laboratories, under the DSS Contract No. 02SQ.23440-4-9283-6 entitled "Pre-Engineering Assessment of ENERSOLVE Demonstration Project - Dairy Processing Plant".

The ENERSOLVE program under which the present project was carried out is concerned with reducing the consumption of liquid and gaseous fuels used in steam and power generation in older industrial plants. One of the main objectives of the current study was to review the efficiency of energy utilization in Canadian dairy industry with emphasis on fuel utilization in the boiler plant. The study also involved identification of process steps where energy recovery could be feasible and economical.

Milk pasteurization, concentration and drying, whey concentration and drying, cheese cooking, pasteurization and drying, etc. are some of the major energy consuming processes employed by dairy products industry. Since many of the Canadian milk processing and milk products manufacturing facilities were designed and constructed more than twenty years ago limited attention was given to energy conservation and process optimization. However, the rising energy costs over the past decade have made capital expenditure on energy saving systems economically attractive.

The Agropur Coopérative Agro-Alimentaire plant at Notre-Dame-du-Bon-Conseil, Québec was selected for this study as a representative plant in Canadian dairy industry.

The study was divided into the following four phases:

Phase I - Pre-engineering Survey

Phase II - Detailed engineering for modification and cost estimate for Phase III.

Phase III - Retrofit of equipment, commissioning and acceptance by the owner of upgraded systems.

Phase IV - Supervision and monitoring of the upgraded systems for nine months.

This report deals with Phase I of the work. The pre-engineering survey which was carried out during the Phase I of the study involved:

- An evaluation of the major energy intensive process steps and equipment.
- Establishing the energy consumption and sources of energy, thermal efficiences, operating procedures, etc.
- Identification of process steps where substantial amount of energy is available for recovery and utilization in the plant.
- Conceptualizing equipment modifications or retrofitting which could be employed to deliver economic benefit by recovery of waste energy and reduction in fuel consumption.
- Estimating the capital required for retrofitting and revamping modifications to the existing facilities.

The details are presented in subsequent sections of this report.

2.0 PROCESS AND FACILITIES

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2.1 Process Description

Butter, cheese, concentrated milks, dried milk products and frozen desserts constitute the major food items derived from milk. Most dairy products plants produce more than one of these products in order to take advantage of complementary manufacturing operations. Common products combinations include:

a) Butter and nonfat dried milk

b) Fluid milk, ice-cream and cottage cheese

c) Cheese and whey

The Agropur Coopérative Agro-Alimentaire plant at Notre-Dame-du-Bon-Conseil, Québec is the largest dairy products plant in Canada producing mainly, cheese and whey powder.

In 1984, the plant processed about 31 360 000 litres of raw milk to produce cheese, whey, skim milk and dry milk powder. During the same period, approximately, 406 TJ (385 GBtu) of Fuel Oil #6 and between 135 and 270 thousand cubic meters of gaseous fuel generated by waste treatment plant were consumed in the plant. Thus, any effort that could reduce energy consumption by even 5% could have significant impact on the product costs at this plant. The specific energy consumption in terms of kilo-Joules of Fuel Oil No. 6 per litre-of-milk equivalent transformed at this plant, in 1984, was 1304.3 kJ/l.

A brief description of the cheese making process and the details of the specific facility at Notre-Dame-du-Bon-Conseil are presented in the following sections.

CHEESE AND WHEY PRODUCTION

There are two main processes for making cheese: acid coagulation of milk which yields the cottage cheese; and rennet coagulation of milk yielding ripened cheeses. There are about 18 distinct types of cheese, with over 500 named varieties.

The general process for cheese-making involves coagulation of the milk, cutting of the curd, expulsion of the whey, firming of the curd, acid development in the curd either before or after hooping, pressing of the curd to provide final control of the moisture content of the cheese, and salting after desired acid development to stop further acid formation. Of the numerous cheeses made in Canada, Cheddar is the most common utilizing more than 50% of all the milk used in the making of ripened cheeses.

The specific details of the conventional process for making Cheddar cheese are given in Appendix A.

The whey solids, which are recovered as by-product in cheese making, contain significant quantities of proteins and fat (see Appendix A, Table A-2). However, only a small fraction of the by-product wheys are dried due to the low solids content and difficulties in lactose drying. Lactose becomes sticky when heated and it is highly hygroscopic in dry form.

Usually whey is preheated to between 77-105°C and fed to multiple-effect evaporators. In the evaporators the solids content of the whey is increased from about 5.8 - 6.5% to between 40 and 70%. At the Agropur plant whey is concentrated to about 42% in the triple-effect evaporators and subsequently the solids content is raised to about 58% by partially flashing the whey in a concentrator and then in a "finisher".

There are several drying methods and numerous variations of each for producing dry whey powder from the concentrate. At the Agropur plant the whey concentrate is heated and immediately spray dried to about 10-12% moisture. Dried product is sifted in a shaker-dryer to maximize crystallization of lactose and reduce its hygroscopicity. After final drying the dried whey powder containing about 3% moisture is stored in plastic lined bags to prevent moisture absorption and caking.

Dried whey powder finds application as ice-cream mix preparation, source of animal proteins, cheese food additive, etc.

2.2 Energy Consumption

Milk pasteurization, whey concentration and whey drying are the major thermal energy consuming processes in a plant producing cheese and whey. Cheese drying, mainly uses mechanical energy and a smaller proportion of thermal energy.

The Agropur plant at Notre-Dame-du-Bon-Conseil consumed a total of about 491 TJ/y of thermal energy in 1984. The main source of this energy was Fuel Oil #6 which contributed approximately 84.5% of the total energy consumed in the plant.

The energy required for the above-mentioned processes is supplied in the form of steam at about 1034 kPag (150 psig). The boiler plant at the Notre-Dame-du-Bon-Conseil facility has three boilers. The details are presented in Table 2-1. Of these, the largest boiler, supplied by Babcock & Wilcox (B & W), provides the steam required for daily plant operation while the other two boilers are used as "stand-by" and "spare", respectively.

Table 2-1 Boilers Installed at Notre-Dame-du-Bon-Conseil Plant of Agropur Coopérative Agro-Alimentaire

Supplier	Steam Capacity kg/h (lb/h)	Fuel	Installation Year
Scotch Maine	16 000 (35 000)	Oil & Natural Gas or BioGas	1944
Scotch Maine	16 000 (35 000)	Oil	1945
Babcock & Wilcox	36 300 (80 000) D-Type	Oil & Natural Gas or BioGas	1977

Source: Agropur Coopérative Agro-Alimentaire, 1985.

2.3 Equipment and Facilities

The B & W Boiler

The B & W boiler is a conventional pressurized water tube package boiler. The Raskin-Coen burner on this unit, is a standard multiple fuel steam-atomized burner capable of firing both oil and natural gas. Through a separate burner throat, an undetermined flow of biogas is admitted at rates varying between 500 to 1000 m^3/d (the waste treatment plant is designed to produce up to 2000 m^3/d).

The biogas comprises about 80 mol % methane (CH_4), 18 mol % carbon dioxide (CO_2) and traces of impurities.

Combustion Control

The B & W boiler is equipped with the combustion control instrumentation supplied by Bailey.

The combustion air supply is controlled automatically by inlet vanes on the F.D. fan mounted on the boiler front. This arrangement is adequate for the present boiler operation with high excess-air (over 15% excess-air) conditions.

Boiler Blowdown System

The continous blowdown flow from the steam drum is controlled by manual setting of a small regulating valve. There are no arrangements for direct heat recovery using either a heat exchanger for hot water or flash steam recovery system.

Condensate from the steam drum is returned to a hot well which is part of the boiler feed water system.

Auxiliaries

Currently, none of the boilers are equipped with either combustion air preheater or an economiser.

Steam Consumption

The boiler is operated approximately 6500 hours per annum. On an average it generates about 18 000 kg/h (40 000 lb/h) of steam at 1034 kPag (150 psig).

The main use of steam in the plant is in the multiple effect evaporator which concentrates whey from about 6% solids to about 42% solids. Approximately 45 000 kilograms of whey is fed to the concentrator per hour.

The condensate from the first effect is returned to the condensate return drum in the boiler feedwater system. The condensate from the second and third effects and the finisher drums is used in cleaning/wasting process vessels (termed "cow-water").

Spray Dryers

The other major energy consuming processes in the plant are the drying of milk and whey to produce solid products containing about 3% moisture. There are two spray dryers in the plant.

One of the dryers has a capacity to produce about 2300 kilograms of dry milk powder per hour while the other dryer has a capacity to produce about 2800 kilograms of dry whey solids per hour.

The air to these dryers is heated to about 195 - 250°C by propane burners. The exhaust gases from the dryers have temperatures ranging between 70 - 95°C depending upon the process conditions.

Cow-water

As mentioned above, the condensates from the evaporator, concentrator and the finisher drums are returned to the cow-water hold-up tank. The cow-water temperature ranges from 55-60°C. It is used for washing process vessels. The wash operation consists of two cycles: the acid wash cycle and the caustic wash cycle. For the caustic wash cycle 82 - 85°C wash water is required. Therefore, a portion of the cow-water is heated up from 55-60°C to 82-85°C prior to its use in caustic wash.

A portion of pasteurizer condensate also goes to the cow-water reservoir while the rest is sent to water treatment and sewage system.

From the description given above, it is clear that the plant has a potential for recovery of wasted energy and reduction in operating expenses. The proposed modifications to this plant and the economic benefits are discussed in the succeding Chapters.

3.0 PROPOSED MODIFICATIONS

3.0 PROPOSED MODIFICATIONS

The objectives of this study, as outlined in Section 1.0, are to review the design and operations of the selected dairy products facility and carry out a pre-engineering assessment of modifications in the facility that would deliver economic benefit by conservation of energy.

In order to achieve these objectives the relevant data on the boiler plant, and other major process equipment in the Agropur Coopérative Agro-Alimentaire plant at Notre-Dame-du-Bon-Conseil, Québec were gathered during plant visits.

3.1 Steam Generation Section

As described in Section 2.2, the main source of energy in the plant is the Babcock & Wilcox (B & W) boiler which is not equipped with either an air preheater or an economizer. The design data for this boiler which were obtained from Agropur and Babcock & Wilcox (Canada), are briefly presented in Appendix B.

The two Scotch Maine boilers are of much older design and are used very sparingly. These boilers would require substantial alterations to improve their efficiency and such an effort would not be economically justified.

Both the primary boiler fuel (Fuel Oil #6) and the flue gases were analyzed for specific properties (such as compositions, heating value, temperature of the flue gases at the entrance to the stack, etc.). These data are included in Appendix B. Theoretical flue gas calculations are also presented in Appendix B.

A review of the boiler plant design and analysis of the data gathered during plant visits indicated that there are four primary areas in the steam generation plant which have the potential for improvements leading to better utilization of energy and enhancement of boiler efficiency.

These areas are:

- Combustion Air System
- Burner Installation
- Flue Gas Economizer
- Boiler Blowdown System

Combustion Air System

This system consists of a F.D. Fan, mounted on the boiler front, and the wind box to the oil burner. The combustion air supply is controlled automatically by inlet vanes on the F.D. fan.

One way of improving boiler efficiency would be the provision of Ljungstrom type rotary air heater which would heat the combustion air by extracting heat from the flue gases. This arrangement would be desirable as well as economical when the boiler plant is being designed. The larger space required and the substantially high installation costs due to the constrained boiler plant layout, however, make such a retrofit option less desirable. Therefore, such an option is not proposed for the Agropur plant.

Burner Installation

The boiler is equipped with a Raskin-Coen steam-atomized oil burner package of standard design without the Coen Parallel Flow (CPF) low excess-air feature. As the amount of heat lost as sensible heat in the flue gas depends upon the quantity of flue gas it is highly desirable to operate the burner with minimum excess-air. Hence, it is proposed that the existing burner unit be replaced by a Coen multiple fuel CPF burner module which features steam-atomizing of oil and has the capability of accurately matching combustion air requirements with fuel flow rates. Operation with the modified burner unit would reduce the quantity of excess-air from current levels of about 15% to about 5%. The new design would thus reduce the loss of sensible heat in boiler flue gas.

Flue Gas Economizer

The flue gases exit from the boiler without any heat recovery, consequently, exit gas temperatures of 370°C plus have been recorded. This implies that a substantial amount of heat is lost from this facility. There are several alternatives for recovering the wasted energy. One of the alternatives, combustion air preheater was discussed above under combustion/air system.

The second alternative is to use an economizer type heat exchanger to recover the wasted sensible heat for heating boiler feedwater.

The third alternative is to use a flue gas condensation system which would recover not only the sensible heat in the flue gases but also the latent heat of the water vapour present in the flue gases.

Both the second and third alternatives were investigated further during the course of this study.

The specific design load conditions for the economizer are presented in Appendix C. The flue gas temperature at the economizer exit is a critical factor in the economizer design and selection.

The flue gas leaving the boiler would contain significant amounts of corrosive gases such as SO_2, H_2S and vanadium compound produced by the combustion of Fuel Oil #6 in the boiler. The presence of these gases raises the potential danger of pipe corrosion in the colder section of the economizer where deaerated boiler feedwater enters at about 105°C. The temperature of the metal surfaces in this region would be close to the dew point of the acid gases making the metal vulnerable to corrosion. Thus, it is recommended that the inlet temperature of the feedwater be raised above 115°C to safeguard economizer surfaces.

Also the economizer should be by-passed at very low or high load conditions. This is necessary because at low load the flue gases would not have sufficient energy to heat the water and the operating cost per energy recovered would be very high. On the other hand at very high loads the flue gas flow rate would be higher, and thus the boiler feed water may start boiling in the economizer. Arrangement should be made to automatically by-pass the economizer once steam load crosses a certain upper or lower bound.

A cast iron economizer with protected tubes is considered for this application.

Due to the limited space available in the boiler plant it is proposed to install the economizer on the roof with expansion joints and by-pass valves on the stack. The roof-mounted economizer would be self-draining, thereby protecting the economizer from freezing when it is not in use. A small platform will be provided for servicing the economizer. This arrangement of the economizer requires minor changes in the roof supports structure to secure the economizer and associated ducting. The proposed modification of boiler plant incorporating an economizer is shown schematically in Figures 3-1 and 3-2.

The temperature of gases leaving the economizer would be as low as 180°C. The feedwater temperature would be increased by about 35°C to approximately 150°C. There is no danger of a "Steaming" economizer as the temperature of the water leaving the economizer would be well below the water temperature and flashing point in the mud drum (approximately 180°C).

The pressure losses due to friction in the economizer and the breeching would be, approximately, 2 inches of water (gauge). The forced draft fan on the boiler has more than 3 inch margin on net static pressure requirements and about 13% margin on net flow. In addition, the use of a low excess-air burner would reduce the gas flow and the attendant friction losses. Thus, the existing fan can be used for the new arrangement as test block margins for this fan are adequate (see Appendix B).

The third waste heat recovery system considered in this study involved a flue gas condensing heat exchanger which recovers both the sensible heat and the latent heat of the flue

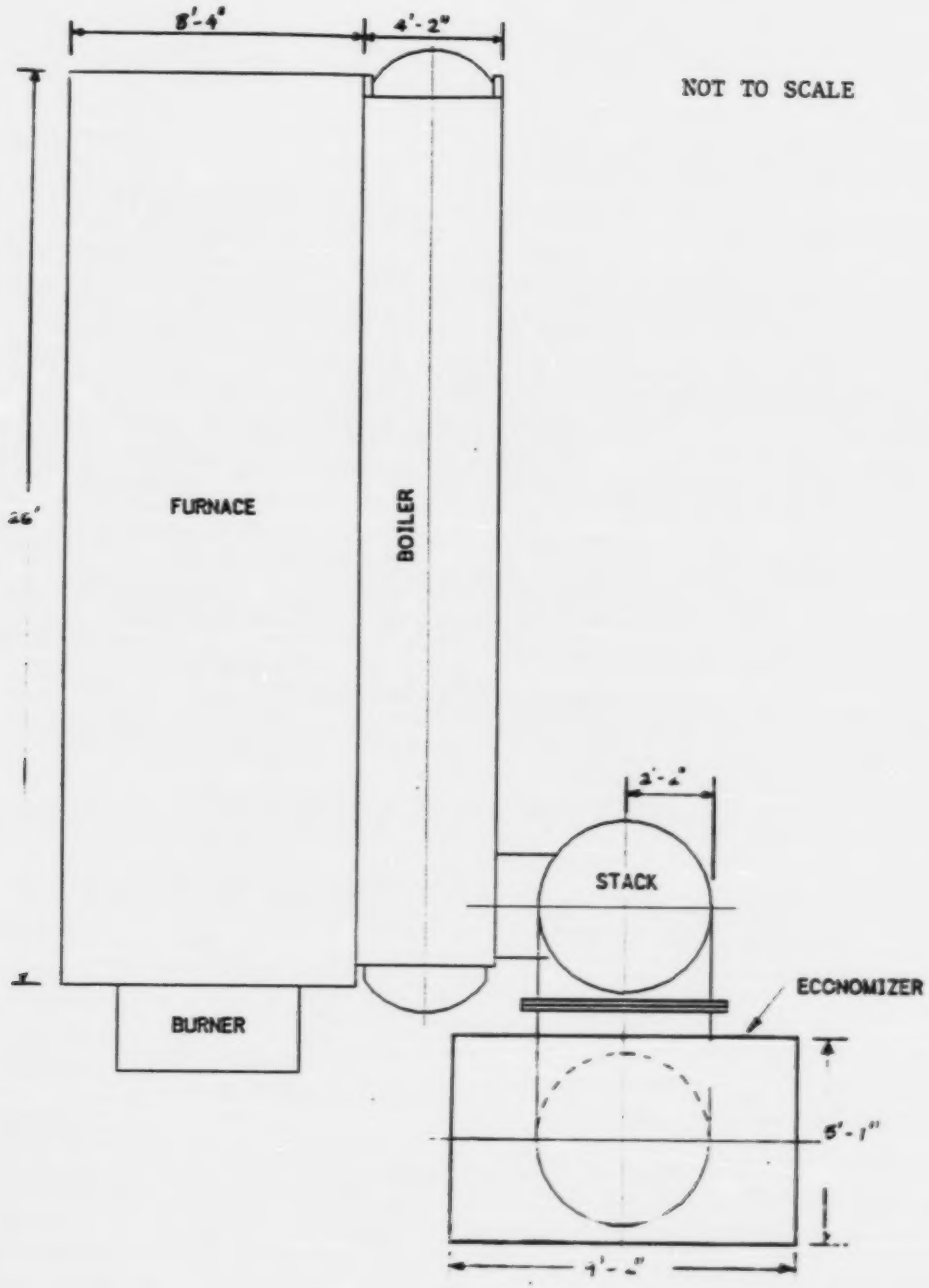


FIGURE 3-1 SCHEMATIC OF THE PROPOSED MODIFICATION OF BOILER PLANT INCORPORATING A NEW EXONOMIZER

NOT TO SCALE

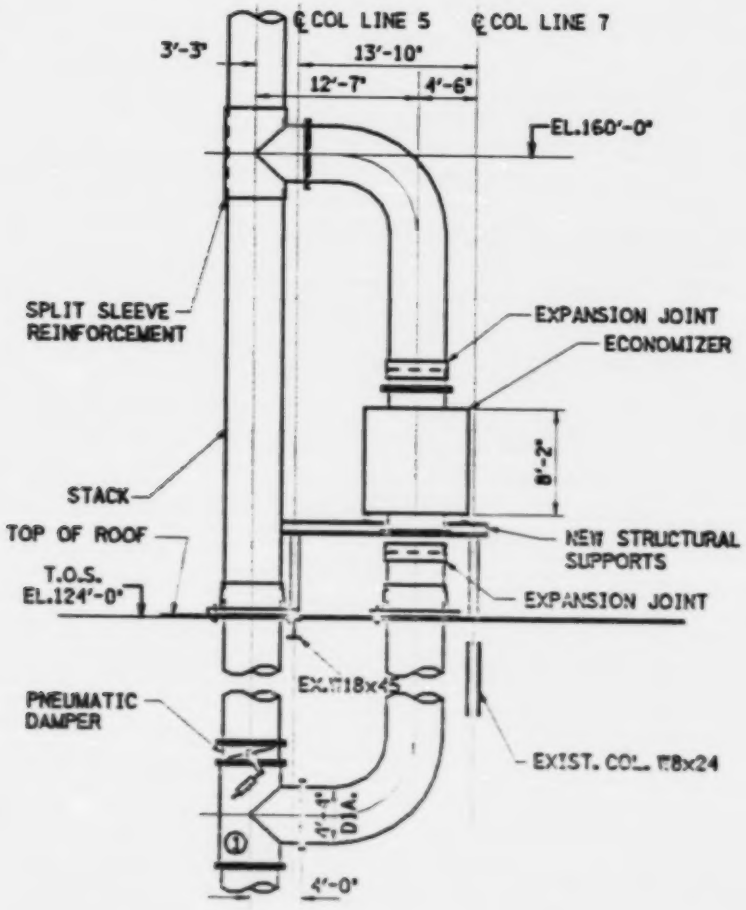


FIGURE 3-2 PROPOSED INSTALLATION OF EXONOMIZER - SKETCH NO. 7465-001-REV.0

gases. Based on the load conditions of the boiler a condensing heat exchanger design was obtained for comparison with the economizer. Predicted performance of the condensing heat exchanger is given in Table 3-1.

The maximum gas inlet temperature for the condensing flue gas system selected here was 260°C while the design temperature of flue gases at boiler exit is about 315°C. Also, in practice the flue gas temperature at the plant under current operating procedures is greater than 340°C. Hence, the gases entering the condensing heat exchanger would have to be diluted with colder air. Under varying design conditions the heat exchanger would raise the temperature of boiler make-up water from 5-15°C (ambient) to about 90-95°C. This water is then fed to the deaerator, the operation of which might have to be modified to obtain the desired quality of boiler feedwater. These complications and the limited space available in the boiler plant suggests that a more detailed study would have to be undertaken including visits to the plant by vendor representatives, prior to making a decision in favour of such a system. Moreover, the capital investment for such a system would be significantly greater than that of the economizer and although the payback periods for such units are claimed to be shorter than conventional units, further investigation of this alternative was considered out of scope for the current phase of this study.

Boiler Blowdown System

The continuous blowdown flow from the steam drum is presently controlled by manual setting of a small regulating valve. Elaborate heat savings devices such as hot water heat exchangers and blowdown flash steam recovery could be added. However, capital expenditures would be far too high and the

Table 3-1 Predicted Performance for Flue Gas Condensing Heat Exchanger

VENDOR	CONDENSING HEAT EXCHANGER CORP.	
DESIGN PARAMETER	WINTER CONDITIONS	SUMMER CONDITIONS
FLUE GAS SIDE		
Flow Rate, kg/h	29 535	29 535
Inlet Temperature, °C	260	260
Outlet Temperature, °C	58	59
Pressure Drop, mm WC	50	50
Dewpoint, °C	60	60
BOILER FEEDWATER SIDE		
Flow Rate, kg/h	21 665	21 665
Inlet Temperature, °C	2	16
Outlet Temperatur, °C	89	93
Pressure Drop, kPag	27	27
ENERGY RECOVERED		
Sensible Heat, MJ/h	5 783	5 814
Latent Heat, MJ/h	2 080	1 227
Total Heat, MJ/h	7 863	7 041

benefit of heat recovery too low for a boiler of this size with relatively low steam output to warrant any such retrofit devices.

Instrumentation

The main factor affecting boiler instrumentation would involve the economizer by-pass control system. The stack would be fitted with CO analyzer and the currently installed O_2 monitoring device would be replaced with appropriate oxygen measurement devices linked to the low excess-air burner. The CO analyser and O_2 monitor would be connected to the microprocessor based boiler control system. Their main function would be to minimize the excess air required for combustion. Semi-automatic or manual controls would also be required for the stack so that the economizer could be by-passed under low load conditions or very high load conditions. Otherwise, the present instrumentation is adequate for a boiler of this size.

3.2 Fuel

Currently, the main fuel at the Notre-Dame-du-Bon-Conseil plant of the Agropur Coopérative Agro-Alimentaire is Fuel Oil #6 (composition data attached as Appendix B). The plant also uses industrial propane delivered in bottles and a small quantity of biogas generated by the waste treatment plant. Taking into account the changes in Québec's energy resources and pricing patterns in the recent years it is proposed that the plant should change the main source of fuel from Fuel Oil #6 to natural gas delivered by a pipeline at the plant gate. Several incentives have been offered by the government and the natural gas supplier in the province. Increasing deregulation of natural gas pricing would deliver additional benefits. In 1984, the average cost of Fuel Oil #6 purchased by the plant was approximately, $5.52/GJ.

Based on data obtained from Energy Mines and Resources, Canada and Gaz Metropolitain, the sole supplier of natural gas in Québec, the industrial customer could obtain natural gas at prices varying from 4.15 to 5.25 $/GJ depending upon the covenants in the contract. This clearly demonstrates the economic benefit of replacing Fuel Oil #6 by natural gas.

The proposed low excess-air burner would readily accept natural gas as a fuel. Additionally, the biogas feed line could be merged with the natural gas supply line at the burner inlet after incorporating necessary regulating devices to control and monitor the flow of the biogas.

3.3 Evaporator and Spray Dryers

In addition to the energy conservation achievable in the steam generation section, there are two other process areas at the Notre-Dame-du-Bon-Conseil plant where energy savings could be delivered: the multiple-effect evaporator and the spray dryers in whey and milk powder production sections.

The information available on the evaporators is not sufficient to get a commplete energy balance and develop a strategy for energy conservation. Current practice calls for a triple-effect evaporator, a concentrator and a finisher. The major energy conservation step consists of using the condensate from the first effect as boiler feedwater.

If major plant reorganization was to be attempted, it would be beneficial to consider the membrane technology options for concentrating whey. The technology is proven and animal feed lactose is produced by this method in several countries.

The multiple-effect evaporators reduce the consumption of steam (and thereby, fuel) by using vapour generated in the evaporators. In general, the temperature of the vapour is increased above the temperature of the feed in the succeeding evaporator vessel by two methods. One of the method is mixing of the low-pressure steam (vapour) with high-pressure steam, i.e., thermal compression. The other method involves mechanical compression of the vapour.

Thermal compression requires steam and therefore, fossil fuels while mechanical recompression uses electrical energy. Hence, thermal compression has been preferred in most plants designed and constructed prior to the 1970's.

However, since 1970's the cost of electrical energy has become highly competitive with the cost of other forms of energy. This is especially true in areas such as Québec which have abundant supply of low-cost hydroelectric energy.

In such economic environment the triple-effect evaporator with thermal compression could be replaced by mechanical vapour compression and a double-effect evaporator coupled with a trim condensor to yield the same product at lower capital investment and operating costs. However, such changes are more cost effective in new plant design rather than in retrofitting existing facilities.

As mentioned previously in Section 2.2 there are two spray dryers in the plant. Neither of these dryers are equipped with waste heat recovery units. The air to each of these dryers is heated with separate propane burners. The temperature of air to the dryers is about 195 - 205°C while the temperature of the water-vapour laden exhaust gases leaving the fines recovery

cyclones ranges between 70 and 95°C depending upon the process conditions. The temperature of ambient air in Québec region varies over a wide range (-10°C in winter to about +25°C in summer months). However, these temperatures are significantly lower than exhaust gases leaving the cyclones. In the existing installation, the hot air leaving the cyclones is cleaned in bag filters and vented.

A substantial amount of energy savings could be effected if the energy available in the spray dryer hot exhaust air is recovered to preheat the air required in drying operations. Such a heat recovery device should be installed by Agropur Coopérative Agro-Alimentaire. However, no design was developed for the air preheater as the data available at the plant indicated that, for this particular facility significantly greater energy savings would result from modifications to the boiler plant and the capital expenditure would be recovered in a shorter time period. The marginal savings resulting from air-to-air heat exchange on the spray dryers could become appreciable if the plant is operated at greater capacity.

3.4 Potential Energy Savings

The potential energy savings generated by incorporating the modification proposed in this study are calculated in Appendix D. In these calculations, use has been made of flue gas analyses data obtained during the course of this Phase of the study.

It is estimated that approximately 48 587 GJ/y of thermal energy is lost under existing plant configuration and operations. The proposed modifications would reduce these losses to approxmately 24 724 GJ/y, thus, delivering energy savings of approximately, 23 863 GJ/y.

On the basis that 95% of this energy is recovered for preheating boiler feedwater, the net reduction in the consumption of in Fuel Oil #6 consumption is about 72.81 kJ/litre-of-milk-equivalent. The consumption of Fuel Oil #6 would be about 1231.53 kJ/litre-of-milk-equivalent.

The energy conservation would result into net savings of approximately $125 000 per annum at Fuel Oil #6 cost of about $5520.538/TJ (see Appendix D).

Substitution of Fuel Oil No. 6 by natural gas would generate additional savings of about $249 000 per annum at natural gas cost of about $0.1815/$m^3$. Thus, the proposed modifications could decrease operating costs by about $374 000 per annum.

4.0 PROJECT COST ESTIMATE

4.0 PROJECT COST ESTIMATE

The capital cost estimate is based on budgetary quotations obtained from equipment vendors as well as in-house data on labour costs, subcontract charges, etc. for installing the equipments with requisite structural modifications to the cheese and whey making plant of Agropur Coopérative Agro-Alimentaire located at Notre-Dame-du-Bon-Conseil, Québec.

The estimated costs for each of the Phases I, II and III are summarized below while the basis of estimation and detailed estimate are presented in Appendix E.

Phase I

The cost of the present pre-engineering assessment is $17 884.00.

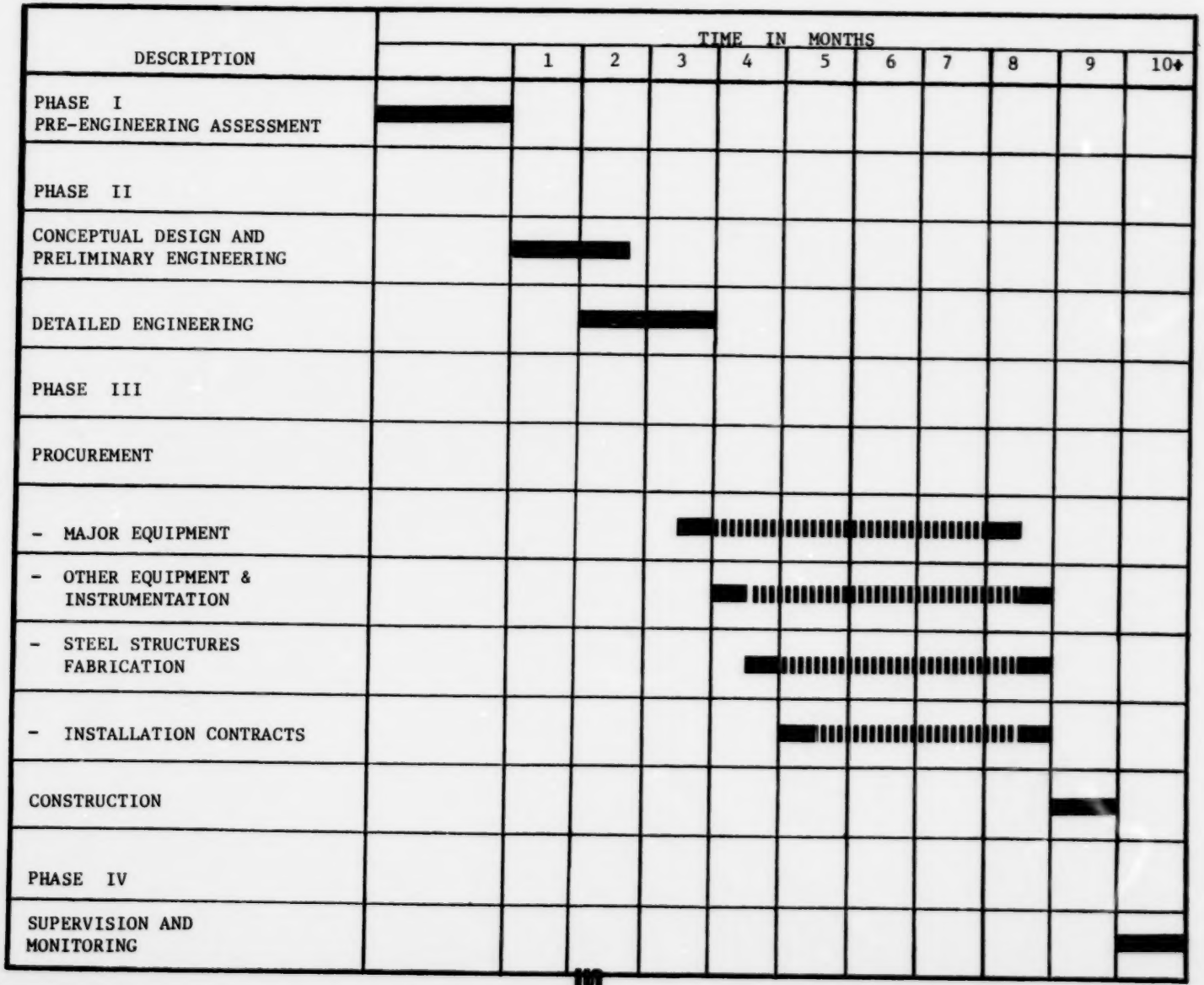
Phase II

The estimate for carrying out the detailed engineering for retrofitting and upgrading the facility is $39 200.00 spread over a period of 14 weeks. The detailed schedule and breakdown of the work to carry out the conceptual design for retrofitting and upgrading the facility is given in Figure 4-1.

Phase III

The retrofitting and upgrading of the facility involves the modification of the stack on the B&W boiler, ducting, and reinforcing the roof of the boiler plant to install a flue gas waste heat recovery economizer, and installing a new CPF low excess-air burner on the boiler.

FIGURE 4.1 SCHEDULE



The estimated cost of the Phase III of the project including installed equipment cost, procurement, project and construction management is $306 800.00. The detailed breakdown of the estimate is given in Appendix E.

Phase IV

The estimated cost of the supervision and monitoring for nine months is $80 000.00. This cost is based on employing one full time engineer for nine months. The cost includes his salary, plus the overhead and fringe benefits, and indirect expenses.

Capital Requirement

The estimated capital requirement is $346 000.00. This estimate is based on budgetary equipment prices quoted by the vendors. Although, it is assumed that the entire economizer would be received as a package from the vendor located in U.S. it is likely that local Canadian vendors could participate (as per Vendor's telex) lowering equipment costs.

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.0 CONCLUSIONS AND RECOMMENDATIONS

Conclusions

On the basis of the preliminary process evaluation and energy balance calculations, the following conclusions may be drawn:

- The B&W boiler installed at this plant is currently operating at an average efficiency of about 79%. Assuming immeasured losses of 1.5%, the net boiler efficiency is 77.5%.

- The existing steam-atomized oil-firing package burner installed on the plant does not have a low excess-air feature. The site tests have indicated that 35% excess air is supplied to the furnace.

- The flue gases leave the boiler at more than 340°C and even at design conditions the flue gas temperature would be about 315°C. This represents a substantial amount of sensible heat which is lost under present boiler plant configuration. Thus, waste heat recovery device such as an air preheater for combustion air or an economizer to heat boiler feedwater could be installed to recover some of the waste energy.

- The boiler blowdown system could be automated, however, the retrofit operation would not be cost effective.

- The multiple effect evaporator for whey concentration is used effectively. However, more recent developments such as separation by membranes or the use of mechanical vapour recompression in conjunction with single or double-effect evaporator could be more economical. The lowering prices of compressor coupled with the low electricity cost in Québec could have significant impact on whey concentration. Nonetheless, such a design is not economically viable for retrofitting existing plants.

- The exhaust air from whey and milk dryers carry both sensible and latent heat of vapourization. This energy could be recovered by using a low-temperature (85-90°C) recuperator to preheat air used in spray drying process.

- The proposed modifications would recover about 23 863 GJ/y at 18 000 kg/h steam generation rate.

- The specific energy consumption (Fuel Oil only) could be lowered by about 5.58% from 1304.34 to 1231.53 kilo-Joules per litre-of-milk-equivalent transformed in the plant.

- The proposed modifications in plant configuration would save approximately $125 000 per annum at a fuel cost of about $5.5205/GJ.

- Substitution of Fuel Oil #6 by natural gas as boiler plant fuel would deliver additional savings of about $249 000 per annum at $0.1815/$m^3$ of natural gas. The total savings could thus amount to $374 000 per annum. A payback of period of between 12 to 18 months is envisaged.

Recommendations

Based on these conclusions, it is recommended that, the Agropur Coopérative Agro-Alimentaire plant at Notre-Dame-du-Bon-Conseil carry out the following modifications in the plant to conserve energy and improve efficiencies:

1) Install a low excess-air multiple fuel burner on the B&W boiler to reduce the consumption of fuel required to heat the inert gases in combustion air from ambient temperature to flue gas temperature by decreasing the amount of inert gases supplied to the furnace.

2) Install an economizer on the B&W boiler to recover energy lost in the flue gas and heat boiler feedwater.

3) Install a CO analyzer in the stack of the B&W boiler to allow efficient control of the combustion process.

4) Develop a procedure for documenting the plant data in a manner suitable for continuous monitoring of energy consumption.

5) Change the main source of energy for the plant from Fuel Oil No. 6 to natural gas.

NOMENCLATURE

NOMENCLATURE

Symbols

C_p	Specific heat, kJ/kg/h
$\dot{m}$	Mass flow rate, kg/h
$\dot{Q}$	Heat flow rate, kJ/h
T	Temperature, °C
$T_.$	Datum temperature, 0°C

Units

°C	Centigrade degree
d	Day
g	Gramme
h	Hour
J	Joule
l	Litre
m	Meter
Pa	Pascal
y	Year

Prefixes

m	Milli, 10^{-3}
k	Kilo, 10^{3}
M	Mega, 10^{6}
G	Giga, 10^{9}
T	Tera, 10^{12}

APPENDICES

APPENDIX A

CHEESE AND WHEY MAKING PROCESS

APPENDIX A

CHEESE AND WHEY MAKING PROCESS

A block diagram of the conventional process of Cheddar cheese manufacture is presented in Figure A-1.

Pasteurized milk is pumped into cheese vats and the temperature is adjusted to about 30-32°C, which is the optimum temperature for starting coagulation. Upon reaching steady state temperature a Lactic starter is added to produce 0.01-0.02% acidity to assist rennet coagulation.

Rennet, or a suitable substitute, are added at a rate of about 0.18-0.20 kg/tonne-of-milk to coagulate milk in about 30 minutes.

In the cutting step the curd is cut into small pieces to promote whey removal. The temperature of the slurry containing the curd is raised to 39-40°C and the cooking process is continued for 40-45 minutes until firm curd is obtained.

The most characteristic step of the process is termed "Cheddaring", where curd is cut into slabs, turned every 15 minutes and piled every 30 minutes to obtain piles of matted curd 3 to 4 high. The curd is matted until acidity reaches about 0.5% (about 5.2 pH). Alternative ways of Cheddaring include:

(a) placing blocks of cheese in a vacuum chamber to promote matting;

(b) matting cheese on a moving belt and then running the curd between two stainless-steel belts under controlled pressure;

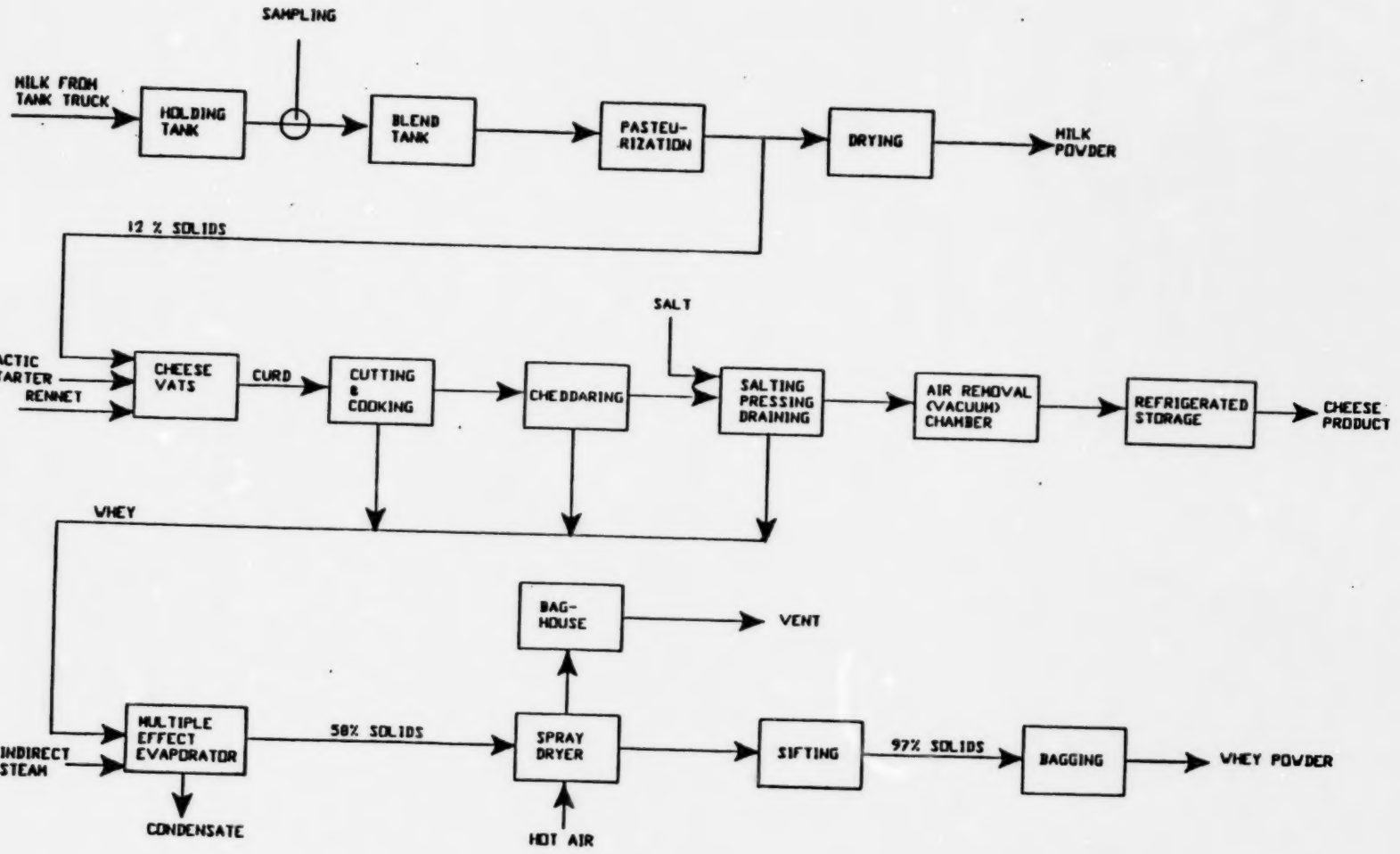


FIGURE A-1 BLOCK DIAGRAM OF A TYPICAL CHEESE WHEY AND POWDERED MILK PRODUCTION

(c) matting the curd in a specially designed tank in the form of a doughnut, a rocking and rotational movement being given to the tank to duplicate the actual Cheddaring process as closely as possible.

Matted Cheddar cheese is prepared for salting and pressing by milling the curd into small pieces. Salt is added in proportion of about 1.5 to 1.8% in finished curd. Salted curd pieces are pressed to remove additional whey packed in plastic bags, boxed and then stored in 7-16°C curing room at 80% humidity for ripening. A typical composition of dry Cheddar cheese is presented in Table A-1. Ripened cheese is further processed as required to produce marketable varieties of Cheddar cheese foods.

The whey produced during draining and pressing stages of curd has approximately 5.8 to 6.5% solids. The composition and physical characteristics of wheys differ according to the composition of milk, method of curd coagulation such as enzyme or acid, type of cheese, etc. A typical whey analysis is given in Table A-2. The whey is dried and the solids are packed in plastic-lined bags to prevent moisture absorption.

Table A-1 Typical Composition of Dry Cheddar Cheese

Component	Per Cent
Milk Fat	50 to 54
Proteins	36 to 42
Carbohydrates	3 to 4
Ash	3 to 4
Moisture	2 to 5

Source: Hall, C.W., and Hedrick, T.I., "Drying of Milk and Milk Products", Avi Publishing, Westport, Connecticut (1971).

Table A-2 Typical Composition of Dry Whey Solids

Component	Per Cent
Lactose	65.0 to 88.0
Proteins	1.0 to 17.0
Ash	0.7 to 10.0
Fat	0.5 to 2.0
Moisture	2.0 to 15.0
Lactic Acid	0.1 to 12.0

Source: Hall, C.W., and Hedrick, T.I., "Drying of Milk and Milk Products", Avi Publishing, Westport, Connecticut (1971).

APPENDIX B

SPECIFICATIONS OF THE BABCOCK & WILCOX BOILER AND THEORETICAL FLUE GAS CALCULATIONS

APPENDIX B

SPECIFICATIONS OF THE BABCOCK & WILCOX BOILER AND

THEORETICAL FLUE GAS CALCULATIONS

The specifications of the Babock & Wilcox package boiler installed at the Notre-Dame-du-Bon-Conseil plant of Agropur Coopérative Agro-Alimentaire are given in Table B-1.

Theoretical Flue Gas Calculations

The fuel oil ultimate analysis is given in Table B-2. The theoretical flue gas obtained by combustion of one kilogram of Fuel Oil #6 is calculated below.

Carbon Dioxide (CO_2)

Reaction	:	C +	O_2 =	CO_2
Moles	:	12.01	32.00	44.01
1 kg of fuel	=	0.8664	kg of C	
	=	$0.8664 \times \frac{44.01}{12.01}$	kg of CO_2	
	=	3.1749	kg of CO_2	
	=	1.6159	Nm^3 of CO_2	
Oxygen Required	=	3.1749 - 0.8664		
	=	2.3085	kg of O_2/kg of fuel	

Table B-1 Specifications of the Babcock & Wilcox Boiler

Type	Water Tube
Steam	Saturated
Design Presure, kPa	1724
Steam Pressure at Outlet, kPa	1034
Capacity, kg/h continous	36 287
Type of Fuel	No. 6 Fuel Oil
Total Heating Surface, m^2-ABMA	450.58
Flue Gas at Exit, kg/h	42 360
Flue Gas Temperature, °C	321
F.D. Fan Test Block	
Air Flow, kg/h	45 585
Pressure Drop, inches Water (g)	15

Source: Agropur Cooperative Agro-Alimentaire, 1985.

Table B-2 Fuel Analysis

Type of Fuel	No. 6 Fuel Oil
Ultimate Analysis, wt%	
Carbon	86.64
Hydrogen	10.39
Nitrogen	0.28
Oxygen	0.15
Sulphur	1.85
Gross Heat of Combustion, kJ/kg	42 406

Notes:

1. Heat of Combustion obtained according to ASTM D 240.
2. Sulphur content measured using PGT Model 100 X-ray sulphur analyzer.

Source: Energy, Mines and Resources Canada, Petroleum and Gas Laboratory, Report of Sample Analysis to SNC, June 27th, 1985.

Water Vapour (H_2O)

Reaction	:	H_2 +	$0.5O_2$ =	CO_2
Moles	:	2.02	16.00	18.02
1 kg of fuel	=	0.1039	kg of H_2	
	=	0.1039 X $\frac{18.02}{2.02}$	kg of H_2O	
	=	0.9269	kg of H_2O	
	=	1.1522	Nm^3 of H_2O	
Oxygen Required	=	0.9269 - 0.1039		
	=	0.8230	kg of O_2/kg fuel	

Sulphur Dioxide (SO_2)

Reaction	:	S +	O_2 =	SO_2
Moles	:	32.06	32.00	64.06
1 kg of fuel	=	0.0185	kg of S	
	=	0.0185 X $\frac{64.06}{32.06}$	kg of SO_2	
	=	0.037	kg of SO_2	
	=	0.0129	Nm^3 of SO_2	
Oxygen Required	=	0.0370 - 0.0185		
	=	0.0185	kg of O_2/ kg fuel	

Oxygen (O_2)

Total oxygen required by the combustion reactions given above is,

2.3085 + 0.8230 + 0.0185 = 3.15 kg

Net oxygen required for combustion is,

3.15 - 0.0015 = 3.1485 kg O_2/kg fuel

One kilogram of dry standard air comprises, approximately, 0.2315 kilograms of oxygen. Therefore, the theoretical amount of dry air required for complete combustion of the fuel is,

$$3.1485/0.2315 = 13.6004 \text{ kg air/kg fuel}$$

That is, approximately, 10.5595 Nm^3 of air is required per kilogram of fuel.

Nitrogen (N_2)

The amount of nitrogen in a kilogram of fuel is 2.8 gms. The amount of nitrogen present in the dry theoretical combustion air is 10.4519 kilograms.

Total Flue Gas

The total quantity of flue gas generated by each kilogram of fuel is 14.6004 kilograms.

On volume basis, the total quantity of flue gas is, approximately, 11.1425 Nm^3/kg fuel.

Efficiency Calculations

The boiler efficiency has been calculated by ASME short cut method and by the CCRL Combustion Handbook Technique. Table B-4 shows the efficiency calculations carried out by ASME short cut method.

Figures B-1 to B-5 show efficiency calculations by CCRL Combustion Handbook Technique.

Table B-3 Boiler Flue Gas Analysis

FLow Rate, kg/h	27,936
Temperature, ^{o}C	315
Composition, Vol %, Dry	
Carbon Dioxide	10.90
Carbon Monoxide	0.00
Oxygen	5.80
Nitrogen	83.30

TABLE B-4 EFFICIENCY CALCULATIONS USING ASME SHORTCUT TECHNIQUE (cont'd)

6W

Fuel : WOOD REFUSE
HHV : dry 42406.00

FUEL OIL	KG/S	0.40
HHV DRY REFUSE	kJ/kg	42406.00
MOISTURE IN AIR	kg/kg	0.0000
EXCESS AIR	%wt	35.00
FUEL MOISTURE	%wt	0.00

AIR AND GAS WEIGHTS

	DRY ANALYSIS % by wt	AF ANALYSIS % by wt	AIR kg/kg Fuel	AIR kg/100kg Fuel	CO2 kg/kg Fuel	CO2 kg/100kg Fuel	H2O kg/kg Fuel	H2O kg/100kg Fuel	N2 kg/kg Fuel	N2 kg/100kg Fuel
C	86.64	86.64	11.53	998.70	3.664	317.45		0.00	8.863	767.89
H2	10.39	10.39	34.34	356.83		0.00	8.937	92.86	26.407	274.37
O2	0.15	0.15	-4.32	-0.65		0.00		0.00	-3.320	-0.50
N2	0.28	0.28		0.00		0.00		0.00	1.000	0.28
S	1.85	1.85	4.29	7.93	1.998	3.70		0.00	3.287	6.08
Ash	0.00	0.00		0.00		0.00		0.00		0.00
H2O		0.00		0.00		0.00	1.000	0.00		0.00
TOTALS	99.31	99.31		1362.81		321.15		92.86		1048.12

Air Required	kg/kg AF Fuel	13.63
Excess Air	kg/kg AF Fuel	4.77
Total Dry Air	kg/kg AF Fuel	18.40
Moisture in Air	kg/kg AF Fuel	0.00
Total Air	kg/kg AF Fuel	18.40
Fuel Ash	kg/kg AF Fuel	1.00
Wet Flue Gas	kg/kg AF Fuel	19.40
Moisture	kg/kg AF Fuel	0.93
Dry Gas	kg/kg AF Fuel	18.47

FLUE GAS ANALYSIS

FLUE PRODUCTS	kg/kg Fuel	kg/kg fuel	SPECIFIC VOLUME m3/kg	m3/kg Fuel	% VOL	% VOL DRY
CO2 :	3.174	CO2 : 3.174	0.534	1.70	10.86	11.78
SO2 :	0.037	SO2 : 0.037	0.360	0.01	0.09	0.09
H2O Fuel :	0.929	H2O : 0.929	1.312	1.22	7.80	
H2O Air :	0.000	O2 : 1.104	0.738	0.81	5.22	5.66
N2 :	10.481	N2 : 14.147	0.839	11.87	76.03	82.47
Excess O2 :	1.104					
Excess N2 :	3.666					
TOTAL :	19.391	19.391		15.61	100.00	100.00
	kg/s	sm3/m				
Total Air	7.36	373.77		Spec Vol	0.81	m3/kg
Flue Gas	7.76	374.79		Density	1.2422	kg/m3

TABLE B-4 EFFICIENCY CALCULATIONS USING ASME SHORTCUT TECHNIQUE

EFFICIENCY CALCULATION (Mod 86) - MODIFIED PTC 4.1-6 (1964) SHEET 1 OF 2

TEST NO. : 1
DATE :01 MAR 1986

FUEL :FUEL OIL 6
LOAD : MCR
STEAM FLOW : 5.0 KG/S

PRESSURES & TEMPERATURES

1.Drum Pressure	kPa	1100.00
2.Press at SH outlet	kPa	1034.00
3.Temp at SH outlet	C	182.00
8.Water temp ent econ	C	115.00
9.Steam Quality	ppm	3.00
10.Blr Room Ambient Temp	C	22.00
11.Air Temp Ivg SCAH	C	20.00
12.Fuel Temperature	C	14.00
13.Flue Gas Temp Ivg AH	C	315.00
14.Flue Gas Temp ent AH	C	

UNIT QUANTITIES

15.Enthalpy Sat Liquid	kJ/kg	772.00
16.Enthalpy SH Steam	kJ/kg	2776.00
17.Enthalpy Feedwater	kJ/kg	632.00
20.Delta H : (16-17)	kJ/kg	2144.00
22.Dry Refuse kg/kg AF Fuel	kg/kg	0.00
23.Refuse HV kJ/kg (average)	kJ/kg	0.00
24.Carbon Burned kg/kg AF Fuel	kg/kg	0.87
25.Dry Gas kg/kg AF Fuel	kg/kg	20.01

HOURLY QUANTITIES

26.Water Evaporated	kg/s	5.00
28.AF FUEL	kg/s	0.40
29.Heat Input	kw	16.96
30.Heat in Blowdown	kw	0.00
***Total Heat Output	kw	10.72

FLUE GAS ANALYSIS

32. CO2	%Vol	10.90
33. O2	%Vol	5.80
34. CO	%Vol	0.00
35. N2	%Vol	83.30
36. Excess Air	%	35.06

FUEL ANALYSIS

41. HHV, AF Fuel	kJ/kg	42406
43. C	%Wt	86.64
44. H2	%Wt	10.39
45. O2	%Wt	0.15
46. N2	%Wt	0.28
47. S	%Wt	1.85
40. Ash	%Wt	0.00
37. H20	%Wt	0.00
TOTAL		99.31
MOIST AIR		0.00

CALCULATED LOSSES/EFFICIENCY

65. Dry Gas	%	13.99
66. Moist In Fuel	%	0.00
66A.Moist In Air	%	0.00
67. Moist From H2	%	6.64
68. Unburned Comb.	%	0.00
69. Radiation	%	0.29
70. Unmeasured	%	1.50
71. Total	%	22.42
72. Efficiency	%	77.58

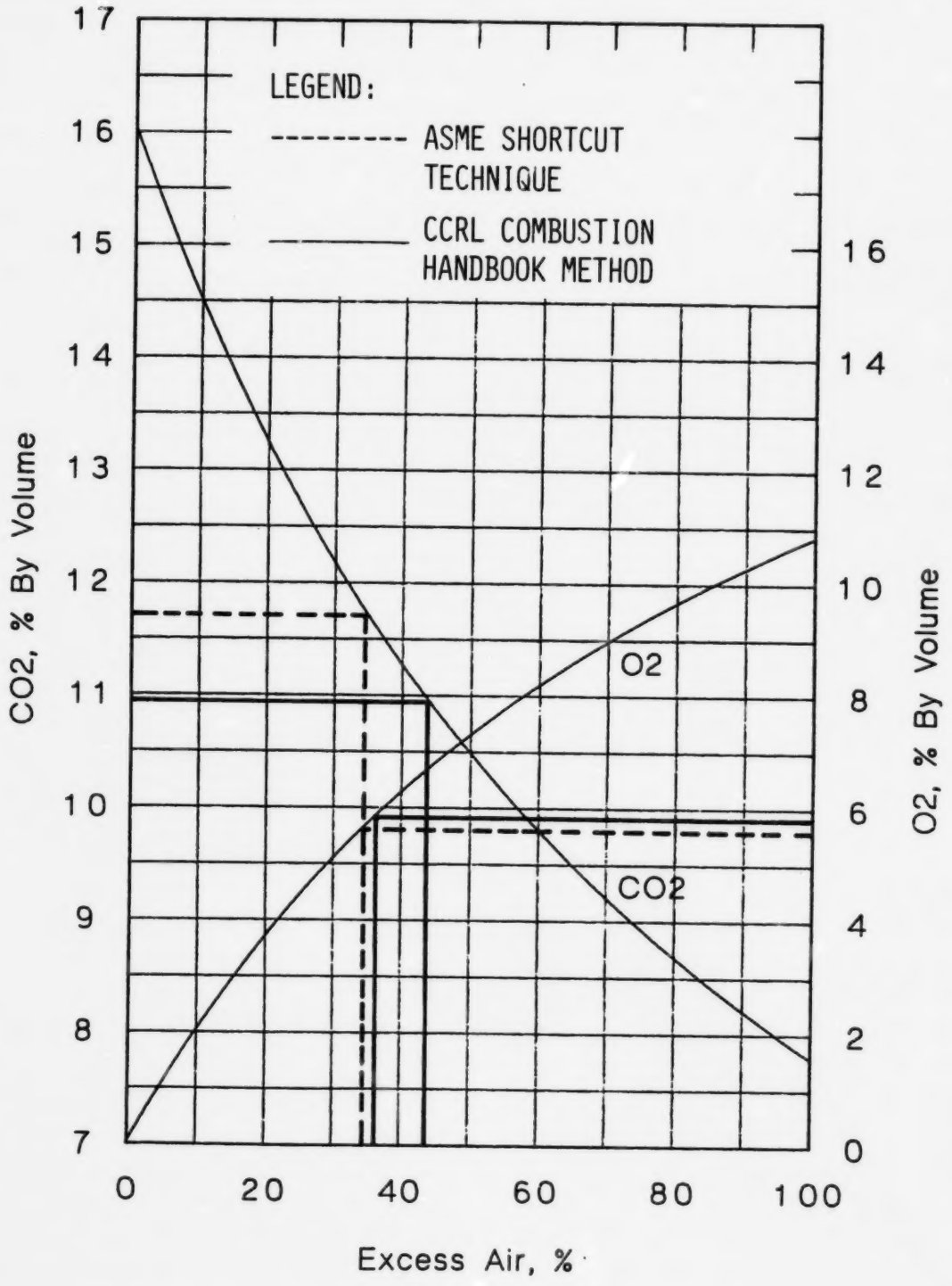


Figure B-1 CO2 and O2 Levels vs Excess Air
Fuel: No. 6 Fuel Oil

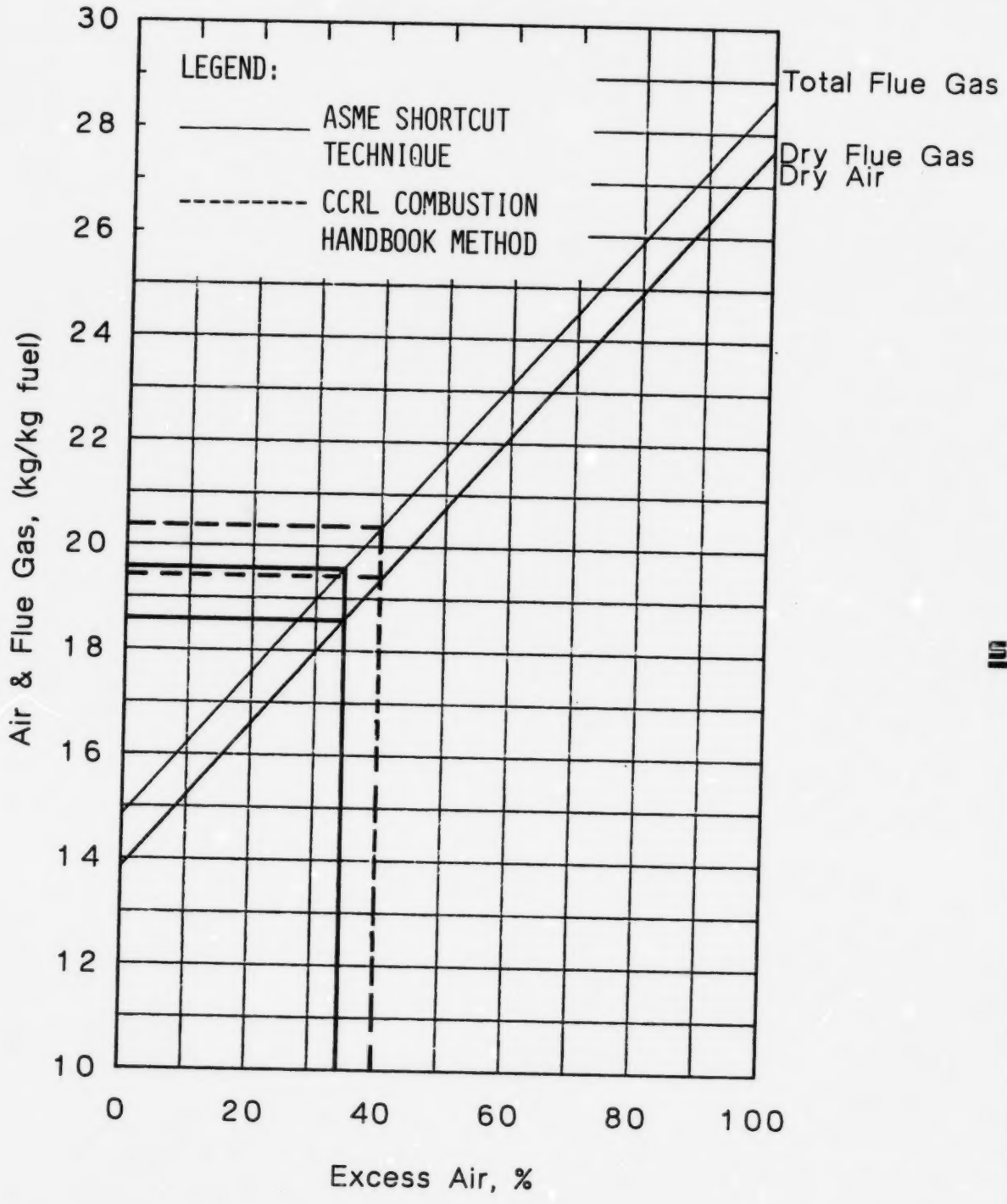


Figure B-2 Combustion Data, Weight Basis
Fuel: No. 6 Fuel Oil

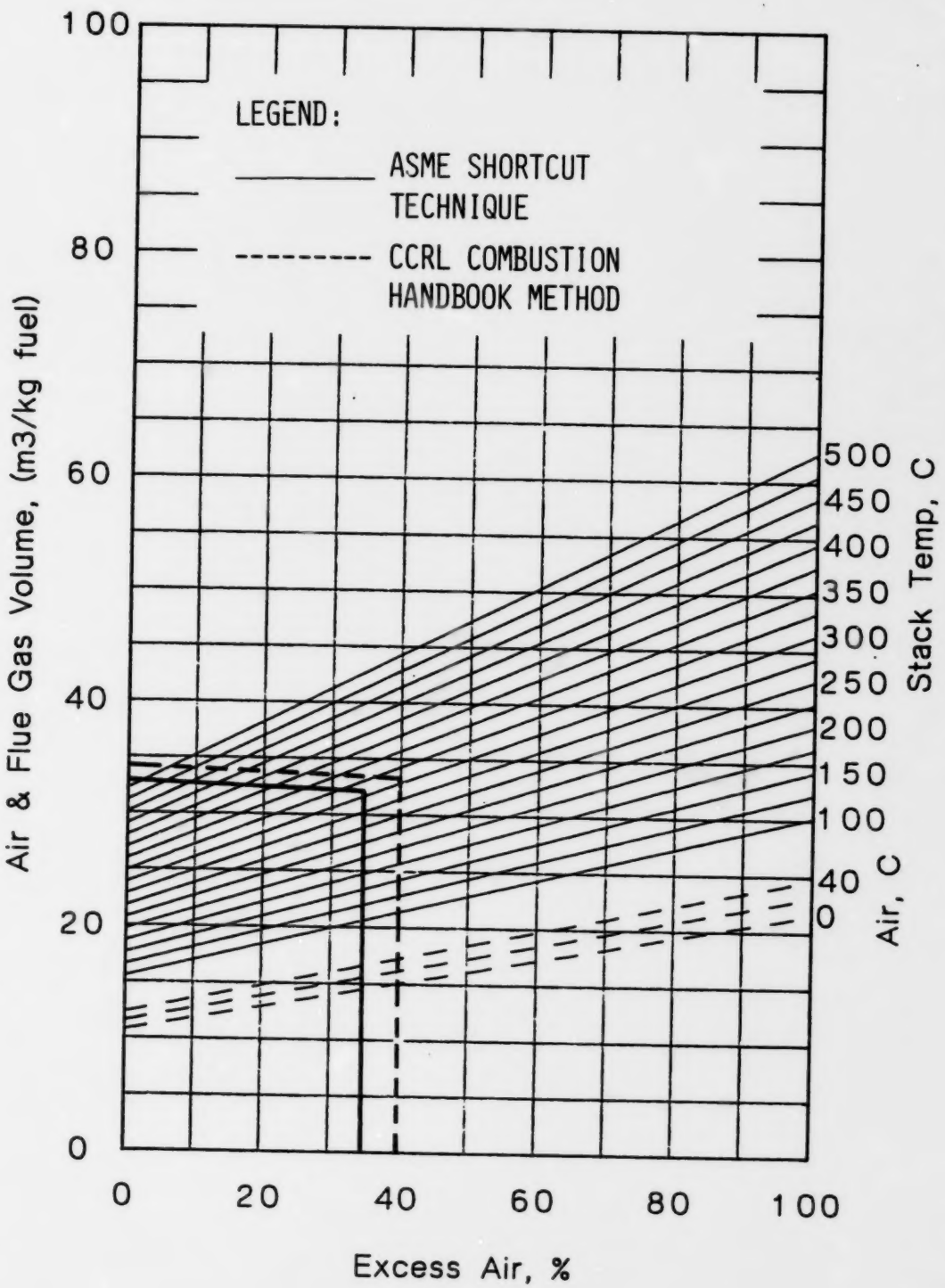


Figure B-3 Combustion Data, Volume Basis
Fuel: No. 6 Fuel Oil

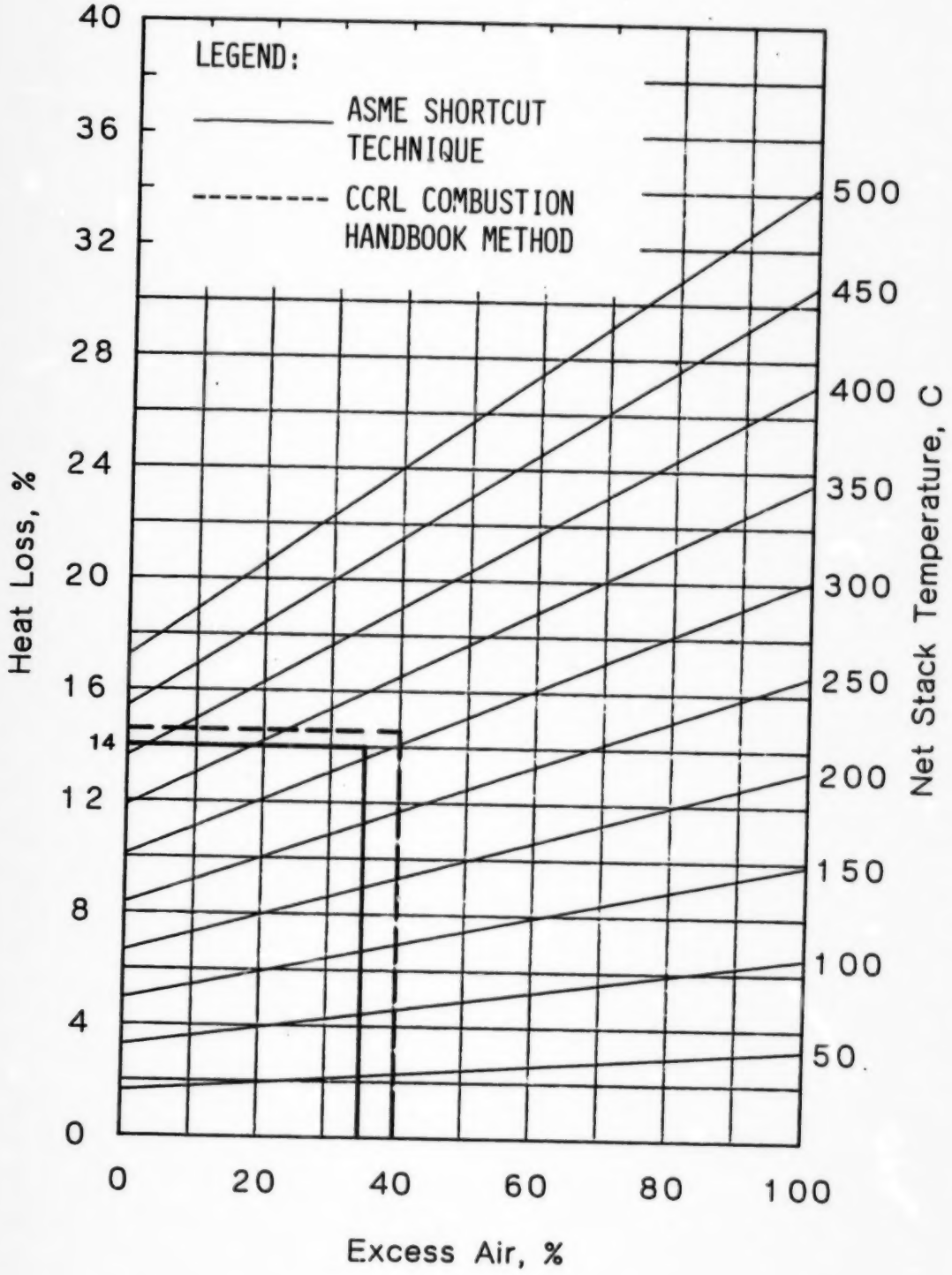


Figure B-4 Dry Flue Gas Loss
Fuel: No. 6 Fuel Oil

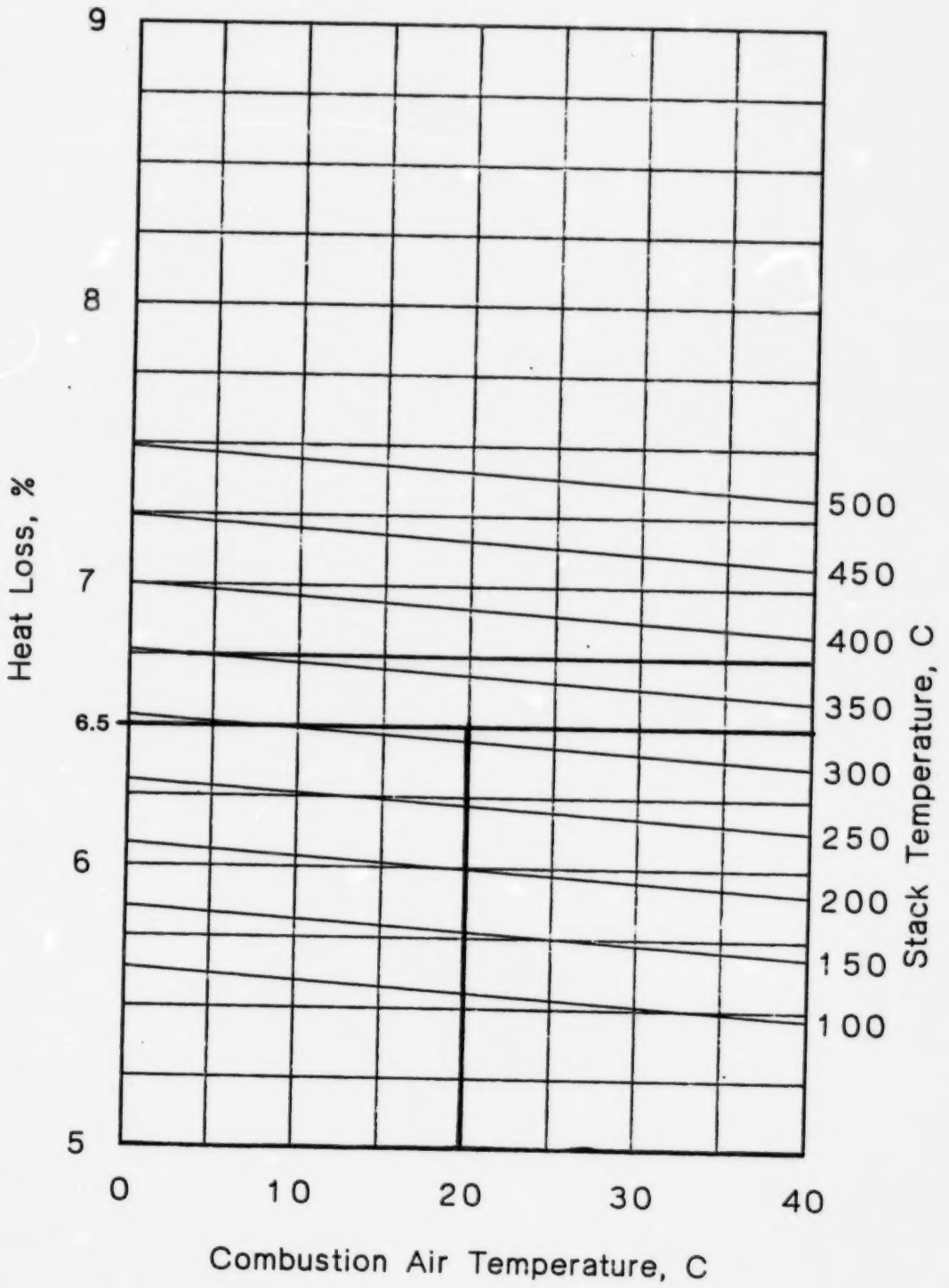


Figure B-5 Hydrogen Loss
Fuel: No. 6 Fuel Oil

APPENDIX C

DESIGN SPECIFICATIONS FOR ECONOMIZER

APPENDIX C
DESIGN SPECIFICATIONS FOR ECONOMIZER

	GAS	LIQUID
Nature	Flue Gas	Water
Flow Rate, kg/h	29 000	29 000
Temperature, °C		
Inlet	315	115
Outlet	182	*
Operating Pressure, kPag		1 034
Fouling Factor	0.002	0.001
Pressure Drop, kPa	--	6.90
Pressure Drop, inches Water (g)	1.0	

* To be supplied by economizer vendor.

Note: Flue gas generated by combustion of either Fuel Oil No. 6 containing about 1.85 wt% sulphur, or natural gas.

APPENDIX D

POTENTIAL SAVINGS FROM ENERGY RECOVERY

APPENDIX D

POTENTIAL SAVINGS FROM ENERGY RECOVERY

The potential economic benefits resulting from energy recovery in the economizer are calculated below on the basis of data supplied by Agropur Coopérative Agro-Alimentaire.

Data

Steam Generated by B & W Boiler, kg/h	
High Load (10% of the usage time)	32 000
Low Load (10% of the usage time)	14 000
Annualized Average	18 000
Annual Operating Time (approximate), h	6 500
Present Flue Gas Temperature (design), ^{o}C	315
Excess-air to B & W Boiler (design), %	15
Flue Gas Specific Heat at 315^{o}C, kJ/kg/^{o}C	1.13
Annual No. 6 Fuel Oil Consumption, m^3/y	9 915
Average Fuel Cost, $\$/m^3$	226.122
Flue Gas Temperature after Economizer, ^{o}C	182
Flue Gas Specific Heat at 182^{o}C, kJ/kg/^{o}C	1.1
Excess-air to Boiler (future),	5

Flue Gas Flow Rate for 18 000 kg steam/h, kg/h

at 15% Excess-air	21 000
at 5% Excess-air	19 000

Calculations

The temperature of the flue gas leaving the economizer would be above 180°C. At this temperature, there is no condensation of water vapour present in the flue gas, hence there would not be any latent heat recovery. The energy balance calculations will, therefore, be based only on sensible heat content of the flue gas.

Let,

$\dot{m}$ = Flue gas mass flow rate, kg/h
Cp = Flue gas specific heat, kJ/kg/h
T = Flue gas temeprature, °C
$\dot{Q}$ = Flue gas sensible heat, kJ/h
T. = Datum temperature, (Assumed 0°C)

Then, the sensible heat lost with flue gas is,

$$\dot{Q} = \dot{m}\, Cp\, (T - T.) \qquad \ldots (1)$$

Using equation (1), the energy lost with flue gas at 18 000 kg/h steam generation with current plant configuration and design conditions is calculated to be,

$\dot{Q}_1$ = 21 000 x 1.13 x 315

$\dot{Q}_1$ = 7 474 950 kJ/' ... (2)

After installing the low excess-air burner and the economizer, the energy lost with the flue gas is calculated to be,

$$\dot{Q}_2 = 19\,000 \times 1.1 \times 182$$

$$\dot{Q}_2 = 3\,803\,800 \text{ kJ/h} \qquad \ldots (3)$$

Thus, a net savings in energy resulting from the modifications could amount to,

$$\Delta\dot{Q} = \dot{Q}_1 - \dot{Q}_2 = 7\,474\,950 - 3\,803\,800$$

$$\Delta\dot{Q} = 3\,671\,150 \text{ kJ/h}$$

Annually, the total recoverable energy would be, approximately,

$$\Delta\dot{Q} = 3.67115 \times 6500 \text{ GJ/y}$$

$$\Delta\dot{Q} = 23\,862.5 \text{ GJ/y} \qquad \ldots (4)$$

Taking into consideration factors such as decrease in heat transfer co-efficients due to fouling, leakage and other non-identifiable energy losses, it might be assumed that approximately 95% of the available energy given by expression (4), above.

The fuel cost in terms of energy units is, $5520.538/TJ. Hence, the annual economic benefit for using the economizer and the low excess-air burner is:

Annual savings = 0.95 x 23.8625 x 5520.538

= 125 147.15 $/y

Thus, the proposed modifications have a potential to deliver net savings of approximately, $125 000 per annum.

The use of natural gas as boiler fuel would increase the potential savings substantially. On the basis that there are no changes in the proposed equipment to be installed, and hence no reduction in capital investment, the substitution of No. 6 Fuel Oil by natural gas would lower the energy cost by $649.20/TJ consumed in the plant.

Annually, about 406 TJ of energy is produced by burning Fuel Oil #6. Thus, additional savings of approximately, $249 000 per annum could be realised by using natural gas instead of Fuel Oil No. 6. The total savings would then amount to approximately, $374 000 per annum.

APPENDIX E

PRELIMINARY CAPITAL COST ESTIMATE

APPENDIX E

PRELIMINARY CAPITAL COST ESTIMATE

A preliminary estimate of the cost of the installation of an economizer, revamping and installing a low excess-air CPF burner, associated piping, mechanical and electrical services, structural modifications to the plant, a platform for servicing the economizer, etc. has been developed.

Base Date and Exchange Rates

The estimated costs are in Canadian dollars as of July 7, 1985 and any quotations received in U.S. dollars have been converted to Canadian prices at a rate of $1.40 Canadian per U.S. dollar.

Basis of Estimate

a) The estimate is based on the attached drawing.

b) Estimates for civil works, structural foundations, electrical, instrumentation and process piping based on layouts and engineering information available from Agropur Coopérative Agro-Alimentaire, Granby, Québec.

c) Budget quotations on all major equipment, with indication of probable freight and insurance charges.

d) No provision has been made for a building or enclosure structure, as per instructions, there being no apparent requirement for same. All equipment and piping has been insulated as per specification.

e) Vendors' services: Vendors' specialist erection supervision and start up services have been allowed on a per diem basis, with an allowance for travel and subsistance.

f) It is presumed that the construction works would be carried out on a management concept, with contracts being awarded to reliable suppliers and/or contractors on a competitive bid basis.

g) Costs shown under the "Labor" columns are subcontractor rates including wages, burdens, fringe benefits, field supervision, temporary facilities, small tools, equipment rental, home office cost, and profit. The hourly labor rate has been fixed at $38.00 for Drummondville, Québec region, and is based on 40-hours week.

h) Costs shown under the "Subcontractor" column include all labor, material, subcontractor indirect cost, overhead and profit.

Engineering and Project Management Services

A separate cost has been indicated for completion of basic design and detailed engineering, home office project management costs, including estimating, cost control, scheduling and procurement activities, construction management, as required.

Contingency

A contingency allowance for undefined costs has been assessed based on information and costs available at the time of estimating. It is intended to cover items of work or elements of cost which will be incurred, but cannot be specifically defined at this time. This cost is not intended to cover changes in the scope of work, either in physical plant, equipment or engineering; force majeur de currency exchange rate fluctuation etc. This cost should be considered as an integral part of the estimate and as such it is expected to be consumed during the progress of the work.

The accuracy of this estimate is $\pm$ 10.0%.

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ESTIMATION DES COÛTS COST ESTIMATE

Client: AGROPUR
Projet/Project: Boiler Stack - Heat Recovery
Lieu/Location: Notre Dame de Bonne Conseil
Secteur/Unité Area/Unit: BOILER HOUSE
Métré/Take-off: R Spencer
Évalué/Priced: R Spencer
Vérifié par/Checked by:
Date: 85.07.10
Page/Sheet De/Of
Contr.: 7465
Subd.:
Sujet Subject:

Code Coût Cost Code	Description	Quan	U	Heures-hommes Manhours U	Heures-hommes Manhours Total	Coût Cost	Coût unitaire Unit Cost Mat'l.	Coût unitaire Unit Cost c/s/ s/c	Main-d'oeuvre Labour	Mat./Equip.	Sous-contrat Sub-contract	Total
	SUMMARY											
	ROOF OPENING FOR BYPASS				177				6730	2690		9420
	ECONOMISER SUPPORT STEEL				112				4260	5200		9460
	BYPASS DUCTS				248				9420	58890	14500	83810
	EQUIPMENT				213				8090	125990		134080
	PIPING				440				18510	5450		23960
	S/T				1190				47010	198220	14500	260730
	~~PST 11% out per H. Divanji 85.07.12. 13.30 hrs~~									21800		~~21800~~
	~~PST 9%~~ " " " "	"	"							19800		~~19800~~
	Engineering, Procurement & Construction Management S/T											54820
	Contingency ±10%.											315550 31550
	PROJECT TOTAL				1190							347000

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ESTIMATION DES COÛTS / COST ESTIMATE

Client: AGROPUR	Secteur/Unité Area/Unit: BOILER HOUSE	Page/Sheet: De/Of	
Projet/Project: Boiler Stack - Heat Recovery	Métré/Take-off: R.Spencer	Vérifié par/Checked by:	Contr.: 7465
Lieu/Location: Notre Dame de Bonne Conseil	Évalué/Priced: R.Spencer	Date:	Subd.: Sujet/Subject:

Code Coût / Cost Code	Description	Quan	U	Heures-hommes Manhours U	Heures-hommes Manhours Total	Coût Cost	Coût unitaire Unit Cost Mat'l	Coût unitaire Unit Cost c/s/s/c	Main-d'œuvre Labour	Mat./Equip	Sous-contrat Sub-contract	Total
	This estimate based on concept sketches C7465.001 & 002 Rev 0 dated 85.07.10.											
	Roof opening for Bypass.											
	Supply and erect working platform 21'-0" x 12'-0" and dismantle	252	SF		72	38	6		2740	1510		4250
	Supply & erect new structural steel frame for stack bypass opening C5 x 6.7 x 24'-3" = 163 W6 x 15.5 x 14'-0 = 217 L 4 x 4 x ¼ x 10'-0 = 66 446 lbs	450	lbs		50	38	1.75		1900	790		2690
	Support existing W6 x 15.5 cut out redundant length remove peice to scrap then remove temporary supports.	1	Job		15	38			570	30		600
	C/F				137				5210	2330		7540

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ESTIMATION DES COÛTS / COST ESTIMATE

Client: AGROPUR
Projet/Project: Boiler Stack - Heat Recovery
Lieu/Location: Notre Dame de Bonne Conseil
Secteur/Unité Area/Unit: BOILERHOUSE
Métré/Take-off: R Spencer
Vérifié par/Checked by:
Évalué/Priced: R Spencer
Date:
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Subd.:
Sujet/Subject:

Code Coût / Cost Code	Description	Quan	U	Heures-hommes Manhours U	Heures-hommes Manhours Total	Coût / Cost	Coût unitaire / Unit Cost Mat'l.	Coût unitaire / Unit Cost c/s/s/c	Main-d'oeuvre / Labour	Mat./Equip.	Sous-contrat / Sub-contract	Total
	B/F				137				5210	2330		7540
	Cut opening in roof for new stack bypass duct hole 5'-10" dia thru roof deck of 4" deep asbestos cement trough deck topped with asphaltic membrane system Clear away demolished materials to scrap.	1	Job		10	38			380			380
	Install cant curb around perimeter of hole and make good the asphaltic membrane roof system	1	Job		30	38			1140	360		1500
	TOTAL - ROOF OPENING FOR BYPASS.				177				6730	2690		9420

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ESTIMATION DES COÛTS / COST ESTIMATE

Client	AGROPUR	Secteur/Unité / Area/Unit	BOILERHOUSE
Projet/Project	Boiler Stack - Heat Recovery	Métré/Take-off	R.Spencer
Lieu/Location	Notre Dame de Bonne Conseil	Evalué/Priced	R.Spencer
Vérifié par/Checked by		Date	
Page/Sheet	De/Of	Contr.	7465
Subd.		Sujet/Subject	

Code Coût / Cost Code	Description	Quan	U	Heures-hommes / Manhours U	Total	Coût / Cost	Coût unitaire / Unit Cost Mat'l	c/s/ s/c	Main-d'oeuvre / Labour	Mat./Equip	Sous-contrat / Sub-contract	Total
	New Structural Steel for supporting the ECONOMISER											
	Cut 5 entries through existing roof and make good after steel and piping has been installed	1	Job		40	35			1520	180		1700
	Supply and Erect new structural steel framing	2870	lbs.		72	38	1	73	2740	5020		7760
	W12 x 27 x 30'	810										
	W 8 x 17 - 24.5'	416										
	Stub HSS 6"x6" - 27'	508										
	C G x 8.2 - 9'	74										
	C 4 x 5.4 x 24'	130										
	L 3½ x 3½ x ¼ x 80'	464										
	Platform Grating 8'x4'	170										
	Handrail 1½x1½ x ¼ L - 70'	164										
	S/T 2726 lbs											
	+ 5% fittings & bolts	134										
	Total 2870 lbs.											
	TOTAL - ECONOMISER SUPPORT STEEL				112				4260	5200		9460

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ESTIMATION DES COÛTS / COST ESTIMATE

Client: AGROPUR
Projet/Project: Boiler Stack - Heat Recovery
Lieu/Location: Notre Dame de Bonne Conseil
Secteur/Unité Area/Unit: BOILERHOUSE
Métré/Take-off: R. Spencer
Vérifié par/Checked by:
Evalué/Priced: R. Spencer
Date:
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Sujet/Subject:

Code Coût / Cost Code	Description	Quan	U	Heures-hommes / Manhours U	Manhours Total	Coût / Cost	Coût unitaire / Unit Cost Mat'l	c/s/ s/c	Main-d'oeuvre / Labour	Mat./Equip.	Sous-contrat / Sub-contract	Total
	BYPASS DUCTS - ASTM 242 (CORTEN)											
	Peice Nº 1 - Flanged TEE	1940	lbs		30	38.00	4.15		1140	8240		9380
	Pt 72" - 3/8 x 14'-0" = 1285											
	" 28" x 3/8 x 14'-0" = 393											
	" 2¼ - ½ x 43' = 164											
	S/T 1842											
	Add 5% of S/T fitts & Weld 98											
	Total 1940 lbs.											
	3 men x 1 day											
	Peice Nº 2 - Lower Duct	3910	lbs		80	38.00	4.25		3040	16620		19660
	Pt 164" - 3/8 x 16'-0" = 3344											
	" 2¼ - ½ x 14'-4" = 56											
	" 40" - 3/8 x 19'-0" = 323											
	S/T 3723											
	Add 5% of S/T fitts & weld 187											
	Total 3910 lbs.											
	4 men x 2½ days											
	Peice Nº 3 - Lower Expansion Joint											
	Pt 12" - 3/8 x 14'-0" = 214	550	lbs		15	38.00	4.25		570	2340		2910
	" 15" - 3/8 x 14'-6" = 280											
	" 2¼ - ½ x 14'-4" = 56											
	Allow for s.s Clamp Bands and Flexible Mat'l	1	Lot		5				190	110		300
	C/F				130				4940	27310		32250

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ESTIMATION DES COÛTS / COST ESTIMATE

Client: AGROPUR
Projet/Project: Boiler Stack Heat Recovery
Lieu/Location: Notre Dame de Bonne Conseil
Secteur/Unité Area/Unit: BOILER HOUSE
Mètre/Take-off: R Spencer
Évalué/Priced: R Spencer
Vérifié par/Checked by:
Date:
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Contr.: 7465
Subd.:
Sujet Subject:

Code Coût Cost Code	Description	Quan	U	Heures-hommes Manhours U	Heures-hommes Manhours Total	Coût Cost	Coût unitaire Unit Cost Mat'l	Coût unitaire Unit Cost c/s/ s/c	Main-d'oeuvre Labour	Mat./Equip	Sous-contrat Sub-contract	Total
	BYPASS DUCTS - (Contd)											
	B/F				130				4940	27310		32250
	Peice N° 4 - Upper Exp'n Joint	320	lbs		15	38	4.25		570	1360		1930
	#1 15 × 3/8 × 14'-0 = 264											
	- 2'4 × 1/2 × 14'-4 = 56											
	Total 320											
	Allow for SS Clamp Bands & Flexible material	1	Lot		5				190	110		300
	Peice N° 5 - Upper Duct	3430	lbs		15		4.25		570	14580		15150
	#1 164 × 3/8 × 14' = 2930											
	- 15 × 3/8 × 14'-6 = 280											
	- 2'4 × 1/2 × 14'-4 = 56											
	S/T 3266											
	Add 5% of S/T Fittings & Weld 164											
	Total 3430 lbs											
	C/F				165				6270	43360		49630

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ESTIMATION DES COÛTS / COST ESTIMATE

Client: AGROPOR
Projet/Project: Boiler Stack-Heat Recovery
Lieu/Location: Notre Dame de Bonne Conseil
Secteur/Unite Area/Unit: BOILERHOUSE
Mètre/Take-off: R.Spencer
Évalue/Priced: R.Spencer
Vérifié par/Checked by:
Date:
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Subd:
Sujet/Subject:

Code Coût / Cost Code	Description	Quan	U	Heures-hommes Manhours U	Heures-hommes Manhours Total	Coût Cost	Coût unitaire Unit Cost Mat'l	Coût unitaire Unit Cost c/s/s/c	Main-d'oeuvre Labour	Mat./Equip	Sous-contrat Sub-contract	Total
	BYPASS DUCTS (Cont'd)											
	B/F				165				6270	43360		49630
	Peice N° 6 - Split Sleeve Reinforcement.	2360	lbs		25	38	4.25		950	10030		10980
	Pt 84 x 3/8 x 14'-0" = 1500											
	" 39 x 3/8 x 14'-0" = 694											
	" 2 1/4 x 1/2 x 14'-4" = 56											
	S/T 2250 lbs											
	Add 5% of S/T Sftgs & weld 110											
	Total 2360 lbs											
	Lateral Roller Supports.	6	Ea		10	38**	120**		380	720		1100
	Pneumatic Damper. complete with pneumatic cylinder & linkage, mounts and compressed air piping	1	Ea		15	38**			570	3880		4450
	Cut entry to existing stack at "A"	1	Job		4	38**			150	-		150
	Cut entry to existing stack at "B"	1	Job		4	38**			150	-		150
	C/F				223				8470	57990		66460

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ESTIMATION DES COÛTS COST ESTIMATE

Client: AGROPUR
Projet/Project: Boiler Stack - Heat Recovery
Lieu/Location: Notre Dame de Bonne Conseil
Secteur/Unite Area/Unit: BOILERHOUSE
Mètre/Take-off: R Spencer
Évalue/Priced: R Spencer
Verifié par/Checked by:
Date:
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Sujet Subject:

Code Coût Cost Code	Description	Quan	U	Heures-hommes Manhours U	Heures-hommes Manhours Total	Coût Cost	Coût unitaire Unit Cost Mat'l	Coût unitaire Unit Cost c/s/s/c	Main-d'oeuvre Labour	Mat /Equip	Sous-contrat Sub-contract	Total
	BYPASS DUCTS. (Cont'd)											
	P/F				223				8470	57990		66460
	Flexitalic or equal flange gaskets, include cutting template	7	Lot		25	38**			950	550		1500
	Flange Bolt Sets (60 per set ss 3/8 ø x 1¼ Lg)	7	Sets		-				-	350		350
	Mobile Crane 55 Ton. Boom 34'-116'	80	hrs					150**			12000	12000
	Hydraulic - Boom Truck 4-5½ Tons 29' Max Reach	50	hrs					50**			2500	2500
	TOTAL - BYPASS DUCTS				248				9420	58890	14500	83810

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ESTIMATION DES COÛTS / COST ESTIMATE

Client: AGROPUR
Projet/Project: Boiler Stack - Heat Recovery
Lieu/Location: Notre Dame de Bonne Conseil
Secteur/Unité Area/Unit: BOILERHOUSE
Métré/Take-off: R Spencer
Vérifié par/Checked by:
Évalué/Priced: R Spencer
Date:
Page/Sheet: De/Of
Contr.: 7465
Subd.:
Sujet Subject:

Code Coût Cost Code	Description	Quan.	U	Heures-hommes Manhours U	Heures-hommes Manhours Total	Coût Cost	Coût unitaire Unit Cost Mat'l.	Coût unitaire Unit Cost c/s/s/c	Main-d'oeuvre Labour	Mat./Equip.	Sous-contrat Sub-contract	Total
	EQUIPMENT											
	Supply & Install an Economiser heat exchanger tube type in square Bundle, Cast Iron protected, Insulation Heating surface 4260 S.F Budget priced in U.S. Dollars.	1	Ea		20	38			760	76440		77200
	Assume shipped in one peice from manufacturer Shipping weight 88,100 lbs.											
	Customs Duty 13.6%									10400		10400
	Freight & Insurance -	1	Lot							2000		2000
	C/F				20				760	88840		89600

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SNC

ESTIMATION DES COÛTS COST ESTIMATE

Client: AGROPUR

Projet/Project: Boiler Stack-Heat Recovery

Lieu/Location: Notre Dame de Bonne Conseil

Secteur/Unité Area/Unit: BOILERHOUSE

Mètre/Take-off: H.Spencer

Vérifié par/Checked by:

Évalué/Priced: P.L. Spencer

Date:

Page/Sheet: De/Of

Contr.: 7465

Subd.:

Sujet Subject:

Code Coût Cost Code	Description	Quan	U	Heures-hommes Manhours U	Heures-hommes Manhours Total	Coût Cost	Coût unitaire Unit Cost Mat'l.	Coût unitaire Unit Cost c/s/s/c	Main-d'oeuvre Labour	Mat./Equip.	Sous-contrat Sub-contract	Total
	EQUIPEMENT (Cont'd) B/F				20				760	88840		89600
	Supply & Install new dual fuel Burner Unit to existing boiler.	1	Ea		145	38**			5510	36350		41860
	Dismantle existing burner and remove to owners store (2 men × 3 days)	1	Job		48	38**			1820			1820
	Freight & Insurance St Eustache / Granby.	1	Lot							800		800
	TOTAL - EQUIPMENT				213				8090	125990		134080

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ESTIMATION DES COÛTS / COST ESTIMATE

Client: AGROPUR
Projet/Project: Boiler Stack - Heat Recovery
Lieu/Location: Notre Dame de Bonne Conseil
Secteur/Unité Area/Unit: BOILERHOUSE .
Métré/Take-off: R Spencer
Évalué/Priced: R Spencer
Vérifié par/Checked by:
Date:
Page/Sheet: De/Of
Contr.: 7465
Subd.:
Sujet Subject:

Code Coût Cost Code	Description	Quan.	U	Heures-hommes Manhours U	Heures-hommes Manhours Total	Coût Cost	Coût unitaire Unit Cost Mat'l.	Coût unitaire Unit Cost c/s/s/c	Main-d'oeuvre Labour	Mat./Equip.	Sous-contrat Sub-contract	Total
	Piping											
	Feedwater supply & return boiler to economiser											
	4" ø Sch 40 CS	120	LF	.44	52	38.00	9.60		1980	1150		3130
	ELLS 4" ø 90°	20	Ea	3.75	75	38.00	17.50		2850	350		3200
	WNRF 4" ø 150#	4	Ea	2.00	8	38.00	25.00		300	100		400
	4" ø Gate Valve	2	Ea	1.0	2		270.00		80	540		620
	Field welds 4" ø	40	Ea	2.0	80	38.00			3040	-		3040
	Bolt-ups 4" ø incl GASKET & BOLTS	4	Ea	1.5	6	38.00			230	-		230
	Steam supply to soot blower 1½" ø Sch 40 CS supply of fittings, valves, hangers & supports included in the per lineal foot price	60	LF	1.25	75	38.00	12.13		2850	730		3580
	Condensate return from soot blower 1" ø Sch 80 CS supply of fittings, valves, hangers & supports included in the per lineal foot price	60	LF	.97	60	38.00	7.60		2280	460		2740
	S/T C/F				358				13610	3330		16940

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ESTIMATION DES COÛTS / COST ESTIMATE

Client: AGROPUR
Projet/Project: Boiler Stack - Heat Recovery
Lieu/Location: Notre Dame de Bome Conseil
Secteur/Unité Area/Unit: BOILER HOUSE
Mètre/Take-off: RSpencer
Évalué/Priced: RSpencer
Vérifié par/Checked by:
Date:
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Code Coût Cost Code	Description	Quan.	U	Heures-hommes Manhours U	Total	Coût Cost	Coût unitaire Unit Cost Mat'l.	c/s/ s/c	Main-d'oeuvre Labour	Mat./Equip.	Sous-contrat Sub-contract	Total
	Piping — s/t c/f				358				13610	3330		16940
	Pipe Test & Clean 13% Lab s/t								1770			1770
	Pipe Insulation 2 inch thick with .006 aluminum jacket											
	4" Dia	215	LF		55	38.00	6.55		2090	1410		3500
	1½ Dia	80	"		14		4.60		540	370		910
	1" Dia	80	"		13		4.25		500	340		840
	TOTAL - PIPING				440				18510	5450		23960

APPENDIX F

DETAILED BOILER PLANT LAYOUT

SNC

APPENDIX

NOT FILMED